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Superpave zoning for Chile
Zonificación superpave para Chile

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Abstract

In Chile, the selection of asphalt binders is based on traditional specifications. Although the Superpave specification has not been implemented yet, it was consider important to make a zoning process of the Chilean territory according to this methodology. This activity relied on the information of 94 weather stations of the Chilean Meteorological Service (DMC in Spanish) and Chile's Water Department (DGA in Spanish), which have reliable data for a minimum of 20 years. Weather data, together with the Köppen climate classification for Chile and the topography of our territory, were used to define approximate zones where the use of each type of asphalt binder is appropriate. Zoning data indicate that most of our territory can be covered by three types of asphalt binders: for the northern and southern regions the use of PG 58-28 is recommended; the central region requires PG 64-22; and finally, the Patagonia and high mountain zones need PG 52-34. In the IX Region, there is a small area in the Andean foothills, where PG 64-34 is required, according to the available climate information and the methodology applied. Classifications PG 64-22, PG 58-28 and PG 52-34 are traditional binders, which were zoned for high-speed traffic conditions and moderate traffic volume.

Keywords: *Pavements' maintenance, superpave, structural layers, asphalt binder, influence of weather station*

Resumen

En Chile la selección de ligantes asfálticos se realiza por especificaciones tradicionales. Aunque aún no se implementa la especificación Superpave, se consideró importante realizar una zonificación del territorio chileno según esta metodología. Para esto se utilizó información de 94 estaciones climáticas de la Dirección Meteorológica de Chile (DMC) y de la Dirección General de Aguas (DGA), las que cuentan con información confiable para un mínimo de 20 años. Los datos meteorológicos, en conjunto con la clasificación climática de Köppen para Chile y la topografía de nuestro territorio, fueron utilizados para definir de manera aproximada las zonas donde es apropiado el uso de cada tipo de ligante asfáltico. Los resultados de la zonificación indican que la mayor parte de nuestro territorio puede cubrirse con tres tipos de ligantes asfálticos: en la zona norte y en el sur del país es recomendable utilizar un PG58-28; para la zona centro se requiere un PG64-22; finalmente para la Patagonia y alta montaña se necesita un PG52-34. Existe una pequeña zona precordillerana en la novena región donde, de acuerdo a la información climática disponible y la metodología utilizada, se requeriría un PG64-34. Las clasificaciones PG64-22, PG58-28 y PG52-34 corresponden a ligantes tradicionales y fueron zonificados para condiciones de circulación de alta velocidad y volúmenes de tránsito moderado.

Palabras clave: Mantenimiento de los pavimentos, superpave, capas estructurales, ligantes asfálticos, influencia de estaciones

1. Introduction

Pavements' maintenance requirements greatly depend on the adequate selection of materials for their respective structural layers. Asphalt binders are susceptible to thermal conditions, that is, their performance strongly depends on the existing weather. For example, a binder can have enough stiffness to resist rutting in a cold zone, but it can show a bad performance in a warm zone concerning the same failure. In recent years, relevant researches have been made in Chile, which address the influence of climate and the advanced characterization of asphalt materials on the performance and maintenance of flexible pavements (Delgadillo et al., 2011; Araya et al., 2012; Delgadillo et al., 2014; García et al., 2014; Osorio et al., 2015).

Considering the above, in 1987, the Strategic Highway Research Program, SHRP, (Kennedy et al., 1994) of the United States began to develop a new specification system for asphalt materials. The final product of the research project was a system known as Superpave (SUperior PERforming Asphalt PAVEments). The main differences and advantages of the new specification in relation to the traditional one are the following:

- *The material is specified considering the temperatures expected on site.*
- *Basic properties of the binder are measured by instruments (rheometers).*
- *It considers the long-term aging of the material.*
- *It considers the load time effect (indirectly).*
- *It considers the traffic volume effect (indirectly).*

Binders are characterized according to the performance expected by three types of failure: rutting, fatigue and thermal cracking. Since each of these failures occur at different temperatures, the asphalt denomination has three characteristic temperatures, expressed in Celsius degrees. For example, a binder labeled PG 64-22 has the following properties:

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- *It resists rutting at temperatures up to Txx = 64°C.*
- *It resists thermal rutting at temperatures up to Tyy = -22°C.*
- *It resists fatigue at temperatures less or equal to* $Tint = \frac{64-22}{2} + 4 = 25°C$

A detailed description of the specifications, including the equipment to be used and parameters to be controlled, can be found in different references (AASHTO, 2015; Asphalt Institute, 2003; ASTM 2015).

The use of Superpave specifications requires to know the pavement temperatures expected on the site's region. This allows selecting a binder that is adequate for that climate zone. This is especially important in a country with such climate diversity as Chile. Previous Superpave zoning efforts for binders were made by Vivanco and Bahía (2005) and by Contreras (2007). The first work used general and very limited climate information, without a statistical analysis of extreme temperatures from the weather stations, which turns it into a more theoretical exercise rather than a practical result. The second work determined PG temperatures of the area between Santiago and Los Angeles, based on data from 38 weather stations, but no specific recommendations were made regarding the use of traditional binders in each zone.

The present work carries out a Superpave zoning in the entire Chilean continental territory, based on the original methodology of the SHRP project (Huber 1994). The outcome of this work is a territorial division by climate zones, which assigns the corresponding traditional asphalt binder to each one of them.

2. Weather station selection

The available information included a total of 137 weather stations with data of extreme daily temperatures, 106 coming from Chile's Water Department (DGA, www.dga.cl) and 31 from the Chilean Meteorological Service (DMC, www.meteochile.gob.cl). However, a minimum of 20 consecutive years of reliable data were needed for the information to be representative and with statistic validity for determining reliabilities. Therefore, it was necessary to apply certain minimum selection criteria, which are detailed below.

Criterion 1: A Complete Year of Relevant Data

The preliminary selection of the PG grade was made based on extreme temperatures; consequently, the stations to be selected should have quality information of the minimum and maximum temperatures. Chile is a country with annual temperature cycles, so it can be assumed that maximum daily temperatures will occur in the summer season, while minimum ones will be registered during the winter months. Considering this, the first two filters defined to select a station were the following:

- *Daily records of minimum temperature for 95% of the days comprised between May 21 and September 21.*
- *Daily records of maximum temperature for 95% of the days comprised between November 21 and March 21.*

Criterion 2: Pending Days for the Maximum Temperature

The relevant temperature for rutting is the maximum moving average of seven consecutive days. Therefore, it was necessary to define an additional criterion for those days with no information on maximum temperature, which consisted in eliminating all those years having two or more days without maximum temperature within any given period of seven consecutive days. In relation to the years having only one day with no record within a given period of seven consecutive days, its value was interpolated between the previous and following day.

Criterion 3: Updated Information

Considering that climate has suffered significant changes in the last 100 years, it was judged that updated data was also a relevant criteria for selecting the stations. Thus, the final selection only included stations that, besides meeting criteria 1 and 2, had information until at least the year 2005.

Total Selected Stations

The total number of weather stations that complied with the aforementioned criteria was 94. This meant to dismiss 43 of the 137 stations originally considered, but this ensured a greater data reliability.

3. PG grade calculation of the selected stations

The extreme temperatures expected on the pavement were calculated, which defines the applicable PG grade for each selected weather station. The original formulas of the Superpave methodology were used (Huber 1994(, which generally yield more conservative results than those of the Long Term Pavement Performance formulas (Mohseni 1998).

Regarding the pavement's minimum temperature, it is assumed that it is the same as the minimum air temperature, so the steps followed by each station were:

1. *Select the minimum (air) temperature daily record for the available year.*
2. *Average the yearly minimum temperatures selected in step 1, which defines the minimum 50% temperature reliability.*
3. *Calculate the deviation of the records selected in step 1, which allows defining the minimum temperatures for other reliabilities.*

The pavement's maximum temperature is calculated based on the maximum air temperature using the following formula (Huber 1994):

$$T_{area} = T_{air} - 0.00618 * \phi^2 + 0.2289 * \phi + 24.4 \quad (1)$$

Where T_{air} is the maximum air temperature, T_{area} is the maximum temperature of the pavement surface. Then, the temperature is calculated at 20 mm depth from the surface $T_{20\,mm}$, which is relevant to define the PG grade, as follows:

$$T_{20\,mm} = 0.955 * T_{area} - 0.8 \quad (2)$$

Where φ is the absolute value of the station's latitude in degrees. The following steps to calculate the each station's maximum temperatures are:

4. *Calculate the average maximum (air) temperature of seven consecutive days for each year.*
5. *Average the temperatures calculated in step 4, which defines the maximum air temperature T_{air} at 50% reliability.*
6. *Calculate the deviation of temperatures calculated in step 4, which allows defining the maximum temperatures for other reliabilities.*
7. *Calculate the maximum daily temperature of the pavement surface $T_{surface}$, entering the T_{air} calculated in step 5 in Equation 1.*
8. *Calculate the maximum temperature at 20 [mm] depth, entering the $T_{surface}$ calculated in step 7 in Equation 2.*
9. *Calculate the standard deviation of the maximum temperature at 20 mm depth from the surface, using the standard deviation of the air temperature calculated in step 6, plus formulas 1 and 2.*

The PG XX-YY grade at 50% reliability for each station will be given by the temperatures calculated in steps 2 (YY) and 8 (XX). If a higher reliability is desired, these temperatures need to be modified using the corresponding standard deviation. For example, at 98% reliability, Superpave recommends subtracting 2 times the standard deviation calculated in step 3 from the temperature YY and add 2 times the standard deviation calculated in step 9 to the temperature XX.

The Superpave classification considers a discrete scale with increases every 6°C; therefore, the obtained temperatures must be approximated to the available grade immediately higher or lower, according to the maximum and minimum temperatures, respectively. Columns Txx and Tyy of Table 1 show the PG grades for each station at 50% and 98% reliabilities.

The extreme temperatures Txx and Tyy determine the requirements to be met by the binder, with the aim of reducing the rutting and thermal cracking susceptibility. Both extreme temperatures are associated to a medium temperature that is characteristic of the Tint location, which is calculated according to the following equation:

$$T_{int.} = \frac{Txx+Tyy}{2} + 4\ [°C] \quad (3)$$

The Tint columns of Table 1 show the temperatures of each station at 50% and 98% reliabilities.

4. Simplified zoning using traditional binders

Selection of Appropriate Binder for each Zone

The previous results show the minimum extreme and medium temperature requirements that binders used in each locality have to meet. Given the large climate variability in our country, these requirements are quite varied. Luckily, good quality conventional binders have PG ranges that frequently allow using the same asphalt binder for different climate subzones. Typically, traditional asphalt binders of acceptable quality may have a difference between maximum and minimum temperature of around 86°C. Modified binders may even have greater temperature ranges. For example: typical, non-modified asphalt binders can exhibit the following classifications:

- *PG 70-16*
- *PG 64-22*
- *PG 58-28*
- *PG 52-34*

In order to determine if a binder is appropriate for a specific climate zone, it must have a high temperature higher than the Txx of the locality, a low temperature lower than the Tyy of the zone and a medium temperature lower than the project site Tint (Kennedy et al., 1994).

Table 1. PG grade and binder assigned to each selected station (I)

Stations		Location			PG									
					50%					98%				
N°	Name	MASL	Lat.	Long.	Txx	Tyy	T° Int.	Binder		Txx	Tyy	T° Int.	Binder	
1	CHACALLUTA, ARICA	63	-18,3514	-70,3358	58	-10	28	58	-28	58	-10	28	58	-28
2	DIEGO ARACENA IQUIQUE	52	-20,5467	-70,1772	58	-10	28	58	-28	58	-10	28	58	-28
3	EL LOA, CALAMA	2293	-22,4953	-69,9044	52	-16	22	58	-28	58	-22	22	58	-28
4	C° MORENO ANTOFAGASTA	113	-23,4503	-70,4411	52	-10	25	58	-28	58	-10	28	58	-28
5	LA FLORIDA, LA SERENA	142	-29,9172	-71,2003	52	-10	25	64	-22	52	-10	25	64	-22
6	SANTO DOMINGO	75	-33,6550	-71,6142	52	-10	25	64	-22	58	-16	25	64	-22
7	Q. NORMAL, SANTIAGO	527	-33,4450	-70,6828	58	-10	28	64	-22	64	-10	31	64	-22
8	E. SANCHEZ, TOBALABA	650	-33,4544	-70,5478	58	-10	28	64	-22	64	-10	31	64	-22
9	PUDAHUEL SANTIAGO	480	-33,5419	-70,7944	58	-10	28	64	-22	64	-16	28	64	-22
10	GENERAL FREIRE, CURICO	225	-34,9664	-71,2167	58	-10	28	64	-22	64	-16	28	64	-22
11	B. O'HIGGINS, CHILLAN	151	-36,5872	-72,0400	58	-10	28	64	-22	64	-16	28	64	-22
12	CARRIEL SUR, CONCEPCION	12	-36,7792	-73,0622	52	-10	25	64	-22	58	-16	25	64	-22
13	MANQUEHUE, TEMUCO	92	-38,7700	-72,6369	58	-10	28	64	-22	64	-22	25	64	-22
14	PICHOY, VALDIVIA	18	-39,6511	-73,0817	52	-10	25	64	-22	64	-16	28	64	-22
15	CAÑAL BAJO, OSORNO	61	-40,6050	-73,0608	52	-10	25	58	-28	58	-22	22	58	-28
16	EL TEPUAL PTO. MONTT	85	-41,4350	-73,0975	52	-10	25	58	-28	58	-16	25	58	-28
17	CHAITEN	70	-42,9311	-72,8289	46	-10	22	58	-28	58	-16	25	58	-28
18	FUTALEUFU	350	-43,1892	-71,8492	52	-16	22	58	-28	58	-22	22	58	-28
19	ALTO PALENA	281	-43,6117	-71,8053	52	-16	22	58	-28	58	-22	22	58	-28
20	PUERTO AYSEN	11	-45,3961	-72,6639	52	-10	25	58	-28	58	-16	25	58	-28
21	TTE. VIDAL, COYHAIQUE	310	-45,5939	-72,1086	52	-22	19	58	-28	58	-28	19	58	-28
22	BALMACEDA (*)	520	-45,9125	-71,6933	52	-28	16	52	-34	58	-40	13	52	-34
23	CHILE CHICO	328	-46,9086	-71,6931	52	-16	22	58	-28	58	-22	22	58	-28
24	LORD COCHRANE	196	-47,2444	-72,5861	52	-22	19	58	-28	58	-28	19	58	-28
25	C. IBAÑEZ, PUNTA ARENAS	39	-53,0050	-70,8439	46	-22	16	52	-34	46	-28	13	52	-34
26	GMZ, PUERTO WILLIAMS	30	-54,9317	-67,6156	46	-16	19	52	-34	46	-22	16	52	-34
27	EL BUITRE AERÓDROMO	110	-18,5119	-70,2842	58	-10	28	58	-28	58	-10	28	58	-28
28	AZAPATA	365	-18,5156	-70,1806	58	-10	28	52	-34	58	-10	28	58	-28
29	CHUNGARA AJATA	4585	-18,2353	-69,1833	46	-16	19	52	-34	46	-22	16	52	-34
30	CODPA	1870	-18,8322	-69,7439	52	-10	25	58	-28	58	-10	28	58	-28
31	COYACAGUA	4013	-20,0531	-68,8075	52	-28	16	52	-34	52	-34	13	52	-34
32	LAGUNILLAS (P. LIRIMA) (*)	4020	-19,9333	-68,8369	46	-28	13	52	-34	52	-40	10	52	-34
33	CASPANA	3260	-22,3367	-68,2122	52	-10	25	58	-28	58	-16	25	58	-28
34	CHIU-CHIU	2524	-22,3378	-68,6367	52	-16	22	58	-28	58	-22	22	58	-28
35	CONCHI EMBALSE	3010	-22,0250	-68,6242	52	-22	19	58	-28	58	-28	19	58	-28
36	LINZOR	4100	-22,2297	-68,0228	46	-22	16	52	-34	46	-28	13	52	-34
37	PARSHALL N 2	3318	-21,9428	-68,5175	52	-16	22	58	-28	52	-22	19	58	-28
38	PEINE	2460	-23,6842	-68,0581	58	-10	28	58	-28	64	-10	31	64	-22
39	CANTO DE AGUA	330	-28,0992	-70,7811	58	-10	28	64	-22	64	-16	28	64	-22
40	LA COMPAÑÍA (VALLENAR)	430	-28,5761	-70,8081	58	-10	28	64	-22	58	-10	28	64	-22
41	LAUTARO EMBALSE	1110	-27,9783	-70,0033	58	-10	28	64	-22	64	-16	28	64	-22
42	LOS LOROS	940	-27,8317	-70,1119	58	-10	28	64	-22	64	-10	31	64	-22
43	SAN FELIX	1150	-28,9311	-70,4614	64	-10	31	64	-22	64	-16	28	64	-22
44	SANTA JUANA	560	-28,6672	-70,6625	58	-10	28	64	-22	58	-10	28	64	-22
45	CAREN	740	-30,8547	-70,7708	58	-10	28	64	-22	64	-10	31	64	-22
46	COGOTI EMBALSE	740	-31,0078	-71,0856	58	-10	28	64	-22	64	-10	31	64	-22
47	EL TRAPICHE	300	-29,3731	-71,1181	58	-10	28	64	-22	58	-10	28	64	-22

Table 1. PG grade and binder assigned to each selected station (II)

Stations		Location			PG									
					50%					98%				
N°	Name	MASL	Lat.	Long.	Txx	Tyy	T° Int.	Binder		Txx	Tyy	T° Int.	Binder	
48	HURTADO	1100	-30,2867	-70,6961	58	-10	28	64	-22	58	-16	25	64	-22
49	ILLAPEL DGA	290	-31,6450	-71,1908	58	-10	28	64	-22	58	-10	28	64	-22
50	LA LAGUNA EMBALSE	3160	-30,2033	-70,0422	58	-22	22	58	-28	58	-28	19	58	-28
51	LA ORTIGA	1560	-30,1939	-70,4819	58	-10	28	58	-28	58	-16	25	58	-28
52	LA TRANQUILLA	1000	-31,9000	-70,6706	58	-10	28	64	-22	58	-16	25	64	-22
53	LAS RAMADAS	1380	-31,0181	-70,5858	58	-10	28	58	-28	64	-16	28	64	-22
54	LOS CONDORES	190	-32,1086	-71,3125	58	-10	28	64	-22	64	-10	31	64	-22
55	PALOMA EMBALSE	320	-30,6958	-71,0361	58	-10	28	64	-22	58	-10	28	64	-22
56	RECOLETA EMBALSE	350	-30,5069	-71,0997	58	-10	28	64	-22	58	-10	28	64	-22
57	RIVADAVIA	820	-29,9772	-70,5617	58	-16	25	64	-22	64	-22	25	64	-22
58	ALICAHUE	750	-32,3408	-70,7528	58	-10	28	64	-22	58	-16	25	64	-22
59	LAGO PEÑUELAS	360	-33,1450	-71,5553	52	-10	25	64	-22	58	-16	25	64	-22
60	LLIU-LLIU EMBALSE	260	-33,0986	-71,2144	58	-10	28	64	-22	64	-10	31	64	-22
61	LOS AROMOS	100	-32,9578	-71,3450	58	-10	28	64	-22	58	-10	28	64	-22
62	QUILLOTA	130	-32,8958	-71,2092	58	-10	28	64	-22	64	-16	28	64	-22
63	VILCUYA	1100	-32,8603	-70,4719	58	-10	28	64	-22	64	-16	28	64	-22
64	CERRO CALAN	848	-33,3950	-70,5367	58	-10	28	64	-22	64	-10	31	64	-22
65	EL YESO EMBALSE	2475	-33,6767	-70,0886	52	-22	19	58	-28	52	-28	16	52	-34
66	LAGUNA ACULEO	360	-33,8858	-70,8775	58	-10	28	64	-22	58	-16	25	64	-22
67	LOS PANGUILES	190	-33,4386	-71,0256	58	-10	28	64	-22	64	-16	28	64	-22
68	MELIPILLA	168	-33,6803	-71,1997	58	-10	28	64	-22	64	-10	31	64	-22
69	PIRQUE	659	-33,6736	-70,5869	58	-16	25	64	-22	58	-22	22	58	-28
70	CONVENIO VIEJO	239	-34,7694	-71,1331	58	-10	28	64	-22	58	-16	25	64	-22
71	ANCOA EMBALSE	421	-35,9106	-71,2958	58	-10	28	64	-22	58	-16	25	64	-22
72	COLORADO	420	-35,6381	-71,2606	58	-16	25	58	-28	58	-22	22	58	-28
73	DIGUA EMBALSE	390	-36,2558	-71,5481	58	-10	28	64	-22	64	-16	28	64	-22
74	PARRAL	175	-36,1878	-71,8283	58	-10	28	64	-22	64	-16	28	64	-22
75	PENCAHUE	55	-35,3725	-71,8325	64	-10	31	64	-22	64	-16	28	64	-22
76	POTRERO GRANDE	445	-35,1833	-71,0978	58	-10	28	58	-28	58	-22	22	58	-28
77	TALCA UC	130	-35,4358	-71,6197	58	-10	28	64	-22	64	-16	28	64	-22
78	CARACOL	610	-36,6511	-71,3950	58	-10	28	64	-22	58	-16	25	64	-22
79	COIHUECO EMBALSE	314	-36,6408	-71,7989	64	-10	31	64	-22	64	-16	28	64	-22
80	DIGUILLIN	670	-36,8686	-71,6425	58	-10	28	64	-22	58	-16	25	64	-22
81	QUILACO	231	-37,6850	-72,0058	58	-10	28	64	-22	64	-22	25	64	-22
82	LIUCURA (*)	1043	-38,6517	-71,0919	64	-34	19	64	-34	64	-40	16	64	-34
83	LONQUIMAY	931	-38,4536	-71,3742	58	-28	19	64	-34	64	-34	19	64	-34
84	MALALCAHUELLO	950	-38,4703	-71,5753	52	-22	19	58	-28	58	-28	19	58	-28
85	PUCON	230	-39,2753	-71,9503	58	-10	28	64	-22	64	-16	28	64	-22
86	PUERTO SAAVEDRA	5	-38,7886	-73,3936	52	-10	25	64	-22	52	-16	22	58	-28
87	TEODORO SCHMITD	13	-39,0278	-73,0781	52	-10	25	64	-22	58	-16	25	58	-28
88	TRAIGUE	234	-38,2561	-72,6536	58	-10	28	64	-22	64	-16	28	64	-22
89	ADOLFO MATTHEI	55	-40,5883	-73,1069	52	-10	25	58	-28	58	-16	25	58	-28
90	COYHAIQUE (E. AGRICOLA)	343	-45,5739	-72,0286	52	-22	19	58	-28	58	-28	19	58	-28
91	PUERTO PUYUHUAPI	10	-44,3228	-72,5597	52	-10	25	58	-28	58	-16	25	58	-28
92	VILLA MAÑIHUALES	150	-45,1733	-72,1478	52	-16	22	58	-28	58	-22	22	58	-28
93	PUNTA ARENAS	5	-53,1233	-70,8772	46	-16	19	52	-34	46	-22	16	52	-34
94	TORRES DEL PAINE	25	-51,1842	-72,9669	46	-22	16	52	-34	52	-28	16	52	-34

The locality of Chile Chico, for example, has an extreme temperature requirement at 50% reliability of PG 52-16 and Tint of 22°C. In this case, it would be appropriate to use the binder PG 58-28 or the binder PG 52-34, which comply with the extreme temperatures and whose medium temperatures are 19°C and 13° respectively. However, it would be appropriate to use the binder PG 64-22, because even if it does fulfill the extreme temperatures, it has a medium temperature of 25°C, which is higher than the Tint of this locality. Consequently, a PG 70-16 should neither be applied.

The "Binder" column of Table 1 shows the binder assigned to each locality in the zoning carried out. The asphalt selection is not necessarily unique for each zone, as we explained earlier. The binders shown in Table 1 were selected so as to keep a relative geographical continuity of the binders recommended, and thus minimize the amount of binders required to cover the entire territory, which favors the implementation and use of the specifications.

Maps for Superpave Binders

In order to make a Superpave zoning based on available temperature data, it is necessary to estimate first the influence area of the weather station. Two criteria were used for this purpose: the climate classification according to the Köppen system for the Chilean territory (Rioseco and Tesser, 2006) as the main criterion and the height above sea level as a complementary criterion. Figure 1 shows the map of Chile according to the Köppen zoning.

Figure 2 shows an example of the Köppen zoning system to delimitate the influence area of the stations available in the area between Coyhaique and Balmaceda on the 50% reliability map. The weather stations closest to Coyhaique required the use of a binder PG 58-28 and they are located within the climate zone classified as Cfc (mild rainy cold without dry season). On the other hand, the weather of Balmaceda indicated the use of a binder PG 52-34 and it is located within the climate zone ET (mild tundra). The limit between both climate zones was used to determine the influence area of each binder, as shown in the Figure.

In the case of stations within a same Köppen climate zone, but with binders of a different PG, their influence zones were determined using the average level curve between the stations. Figure 3 shows the stations Embalse Conchi and Chiu Chiu, which are located within the climate zone BWk' (cold desert climate), which require a binder PG 58-28 at 98% reliability.

Moreover, the Peine station is located within the same climate zone, with a binder requirement of PG 64-22. Once the heights above sea level of the stations were known (indicated in Table 1), the average level curve was used between adjacent stations in order to delimit the influence area of each PG grade, as shown in the Figure. The same criteria was used for the Caspana station.

Figures 4 and 5 show the results of the Superpave zoning made at 50% and 98% reliabilities respectively. At 50% reliability it was possible to cover almost the entire national territory with three grades of traditional binders: PG 64-22, PG 58-28 and PG 52-34. The sole exception appeared on the foothills of the IX Region, corresponding to the influence area of the stations of Liucura and Lonquimay, which would require a modified binder of PG 64-34.

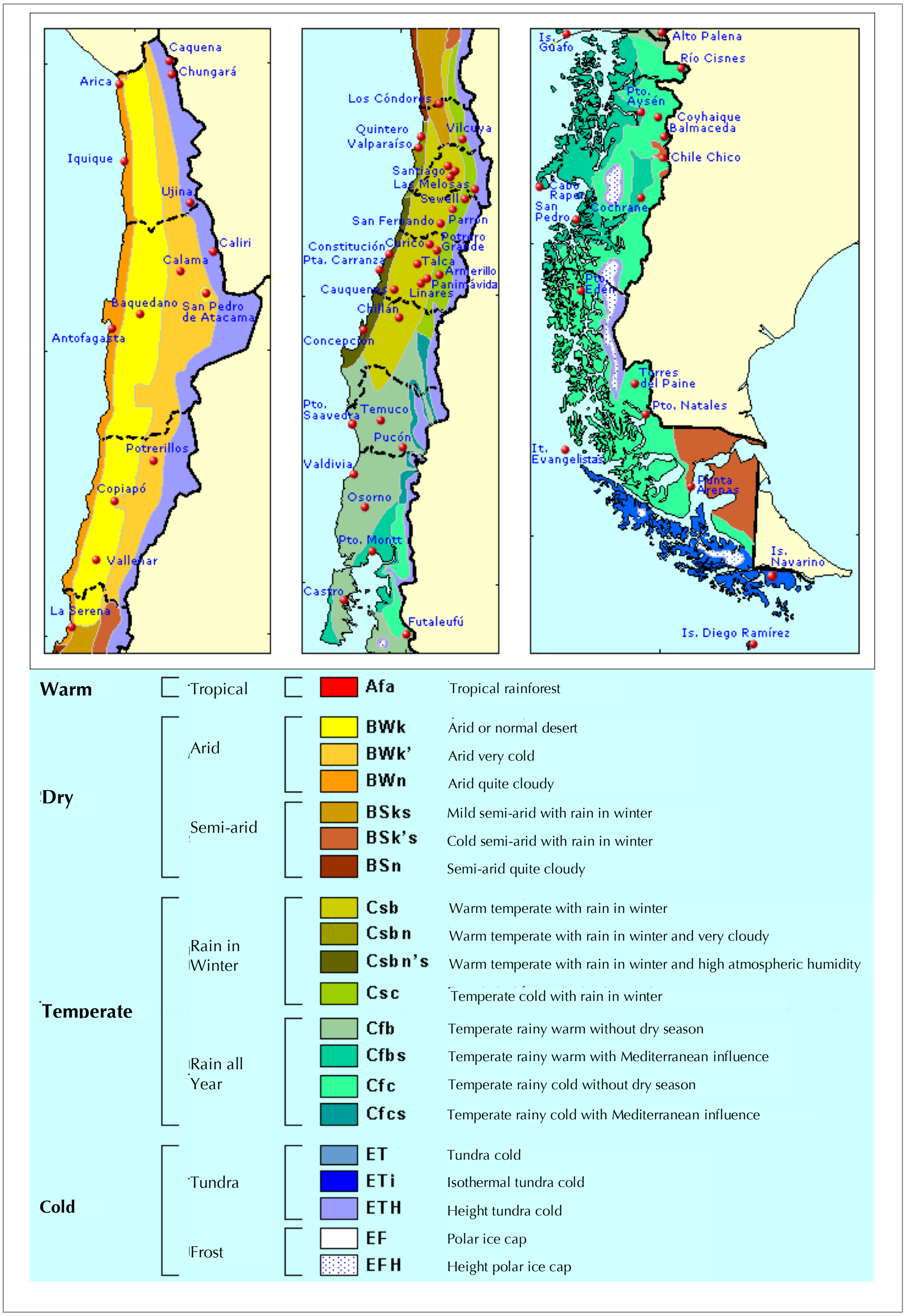

Figure 1. *Köppen Climate Zoning for Chile (Rioseco y Tesser, 2006)*

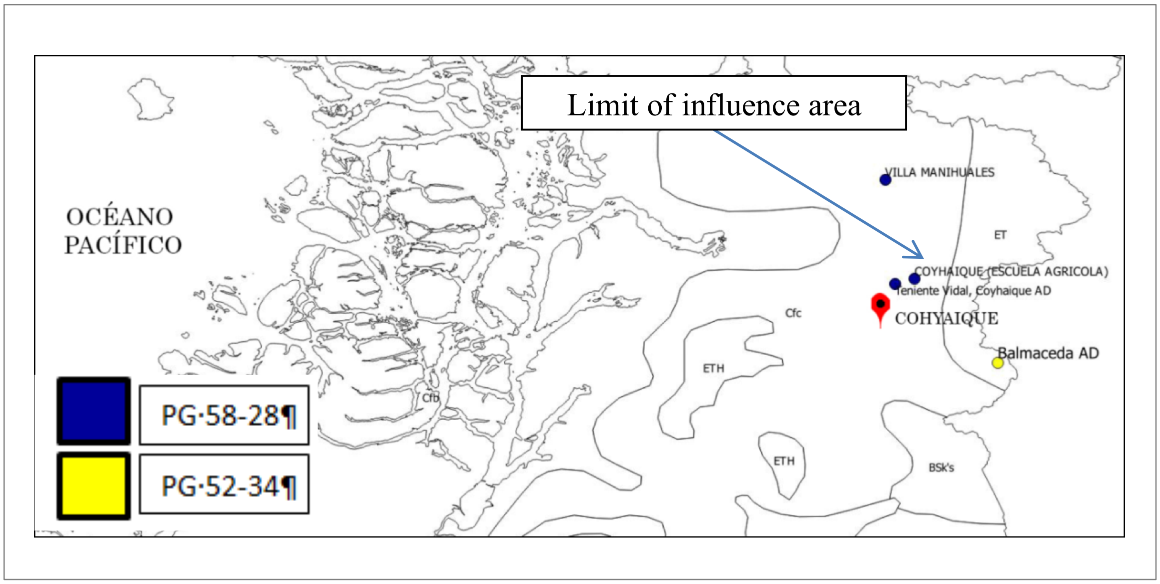

Figure 2. *Use of the Köppen Classification in Superpave Zoning (50% Reliability)*

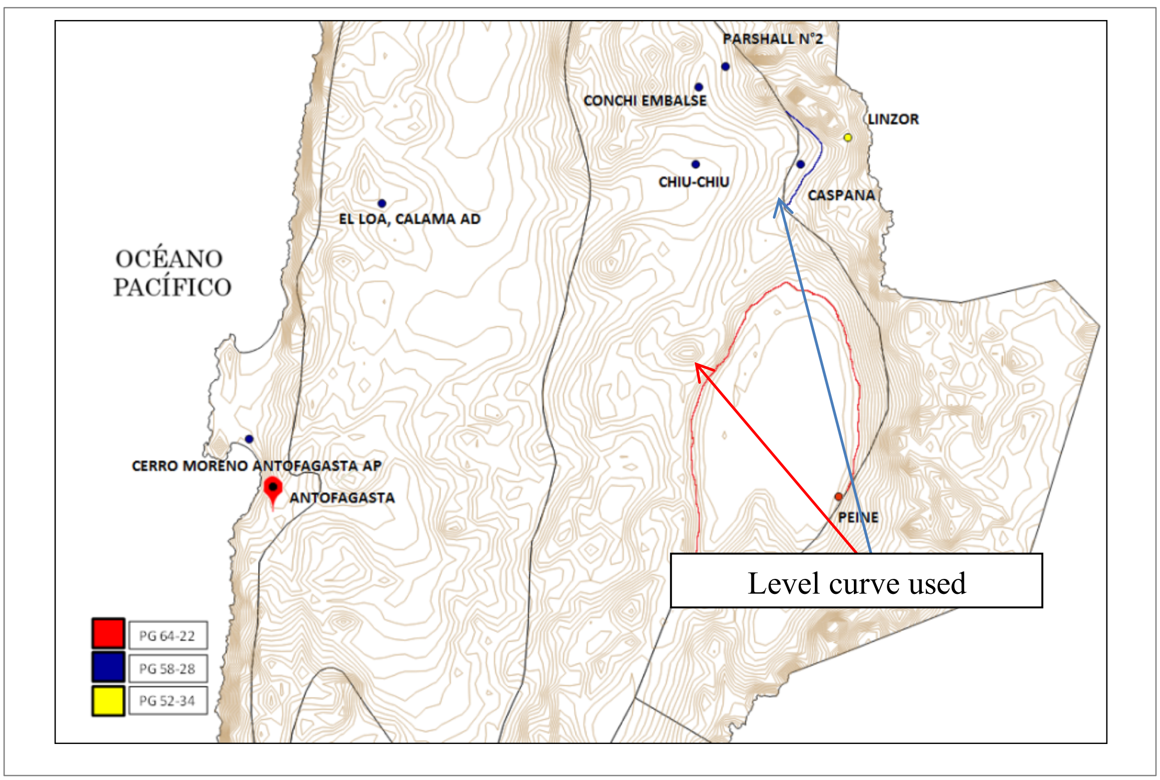

Figure 3. *Example of the Use of Level Curves for Creating the Chilean Superpave Zoning (98% Reliability)*

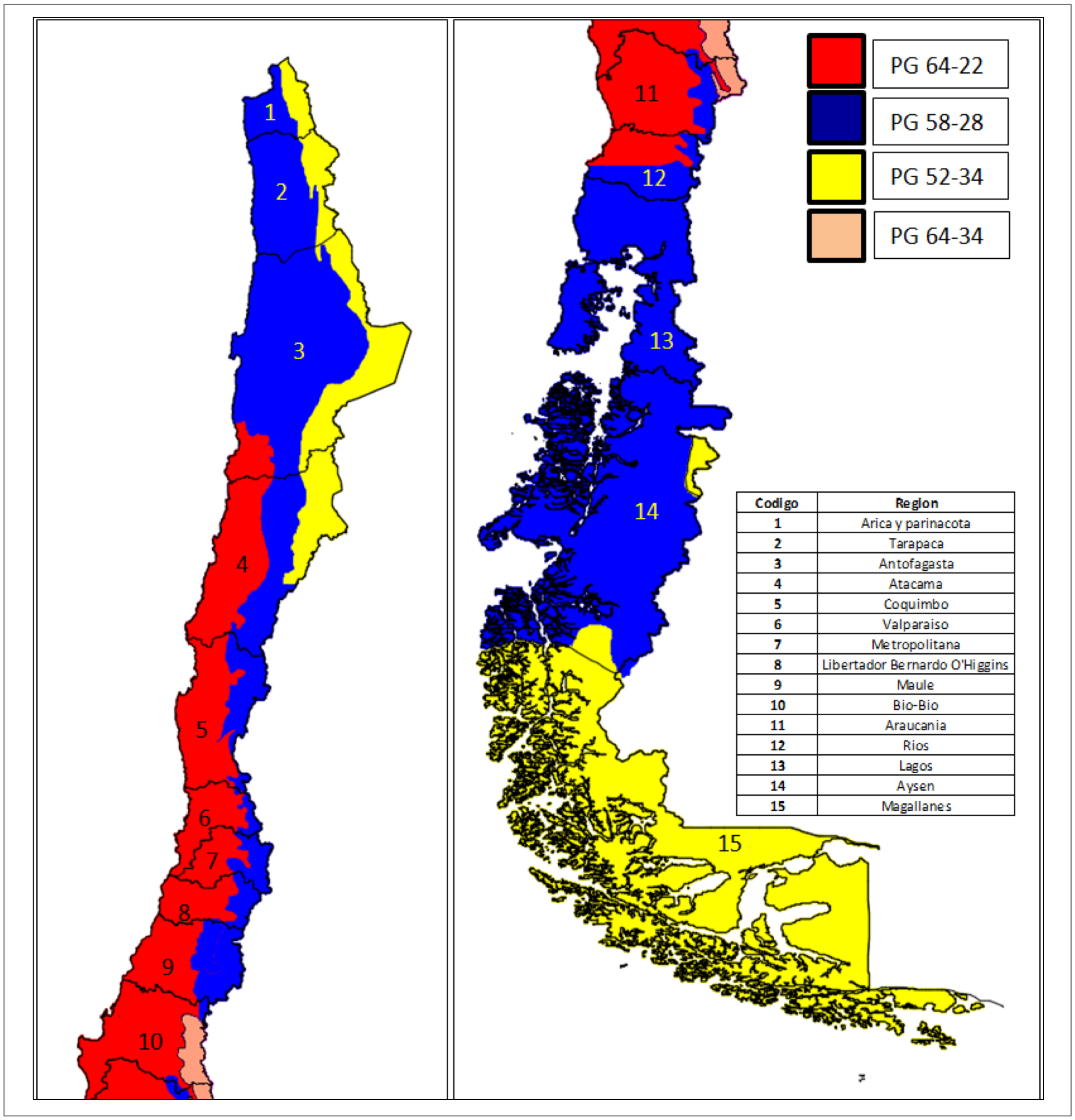

Figure 4. *Superpave Zoning of Chile, 50% Reliability*

The same binders, with some changes in the zoning limits, also obtained 98% reliability in most stations. Only the stations of Balmaceda (theoretical PG 58-40 at 98% reliability), Lagunillas (theoretical PG 52-40 at 98% reliability), and Liucura (theoretical PG 64-40 at 98% reliability) did not reach the 98% reliability when the same four binders considered at 50% reliability were used. The reliability achieved in these stations was:

- *Balmaceda with PG 52-34: 68% reliability for high and low temperature*
- *Lagunillas and Liucura with PG 64-34: 98% reliability for high temperature and 68% reliability for low temperature.*

Notwithstanding the above, the final selection of the PG grade must consider the characteristics of the project itself, the design effect (loading speed) and/or the heavy traffic volume, which can lead to increase one or two PG grades.

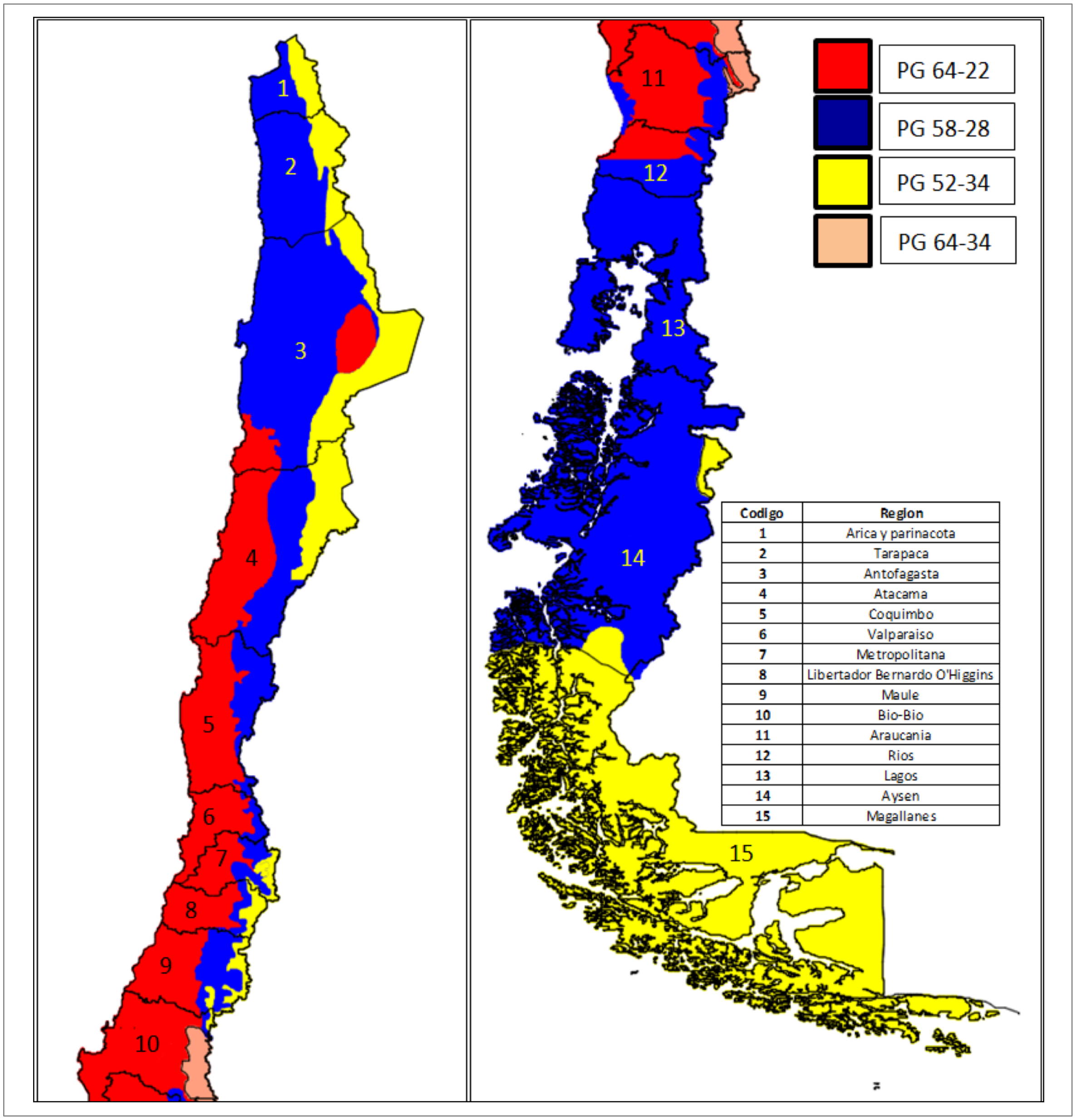

Figure 5. *Superpave Zoning of Chile, 98% reliability*

5. Conclusions

It was possible to make a Superpave zoning at 50% and 98% reliabilities, based on temperature data from 94 Chilean weather stations belonging to the Chilean Meteorological Service and Chile's Water Department. The selected stations relied on useful and updated temperature data.

The Köppen climate zoning and the topography of the Chilean territory were useful criteria to define the influence areas of each weather station, which in the end defined the zones recommended for each PG grade.

Despite the variety of PG grades required for different analyzed stations, it was possible to zone most of the Chilean territory, at 50% reliability and three traditional asphalts: PG 64-22, PG 58-28 and PG 52-34. Only a small foothill area in the IX Region required PG 64-34, which will probably be a modified binder.

The same binders, but modifying some of the limits of the influence areas, could be used for a PG zoning at 98% reliability in most stations. However, the stations of Balmaceda, Lagunillas and Liucura achieved a reliability of just 68% when using these same binders. The first two would require PG 52-40 and the third, PG 64-40, in order to reach a 98% reliability.

The resulting Superpave zoning does not constitute a unique solution. In some localities there is more than one traditional binder that can meet the Superpave requirements. The final selection of the binder included practical considerations, such as giving a relative geographical continuity to recommended binders and minimizing the number of binders needed to cover the entire national territory.

The zoning proposed is consistent with the standard condition defined by Superpave, regarding high-speed traffic conditions and moderate traffic volumes. Slow traffic conditions and high traffic volumes should consider increases in high temperature grades.

Original formulas of the Superpave method were used to obtain the temperatures for each locality, thereby yielding more conservative results than those of the LTPP formulas. Future works should consider a comparison using both formulas and recommendations for low-speed traffic and high traffic volumes.

6. Acknowledgements

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